Interannual variability of Great Lakes ice and internal climate teleconnection patterns

Xuezhi Bai

CILER, University of Michigan

Jia Wang

GLERL/NOAA

Outline

- Background/Motivation
- Data
- Composite atmospheric forcings to high and low ice cover
- Relationship between ice and ENSO (➜ GL atmospheric conditions)
- Relationship between ice and AO/NAO (➜ GL atmospheric conditions)
- Summary

Background

- Ice cover on the Great Lakes affects regional economy, ecosystem and water balance

- Ice cover is also a sensitive indicator of regional climate. It has large inter-annual variability. In 1979, it was 95% and 11% in 2002.

- Possible contributors include leading patterns of internal climate variability (inter-annual and inter-decadal) and long-term trends due to global warming, which is external forcing
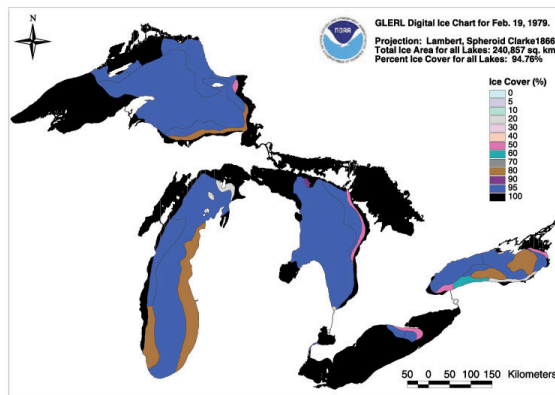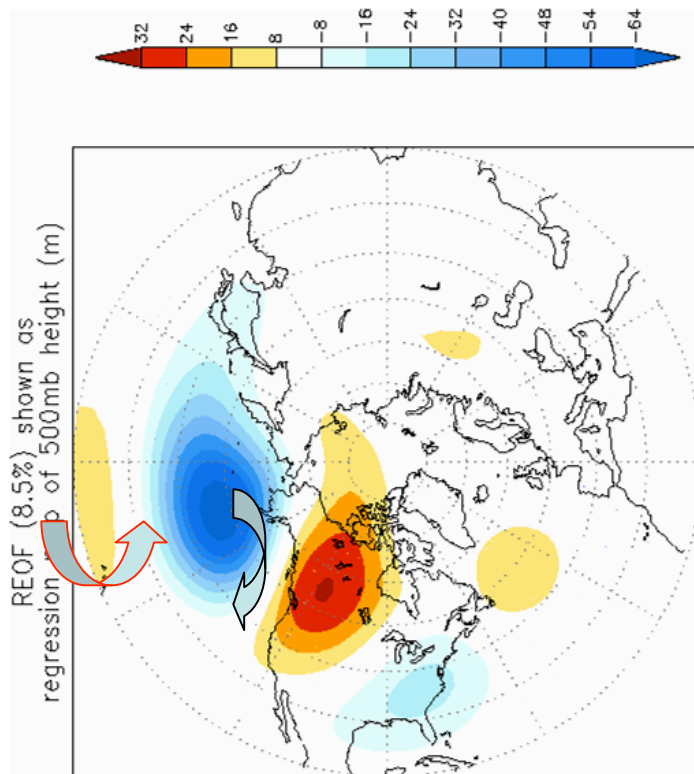

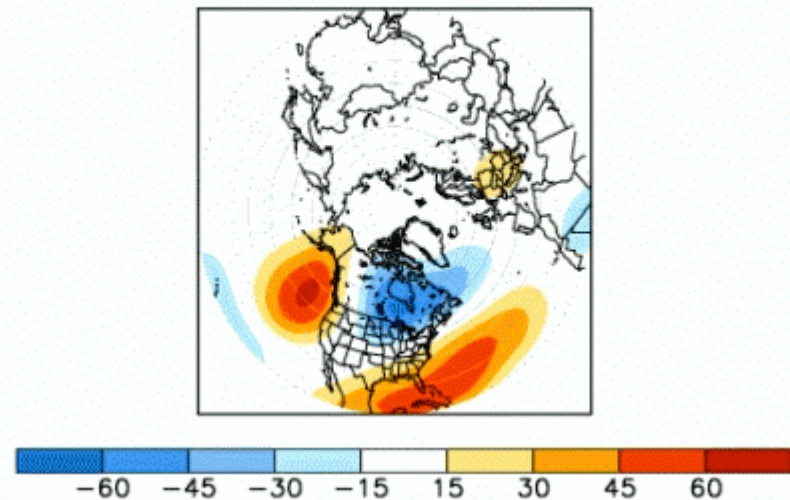
Max in 1979 95%
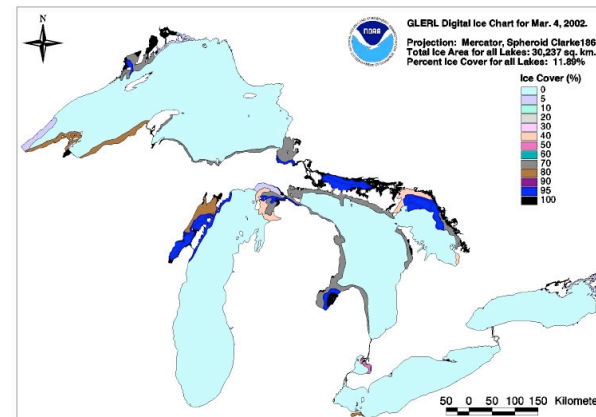
Max in 2002 11%

Background

- Previous studies provided evidences that anomalous ice cover occurred during certain teleconnection patterns, such as **PNA** (Pacific-North America), **TNH** (Tropical-North Hemisphere), ENSO (El Nino and Southern Oscillation), NAO (North Atlantic Oscillation), etc. (Assel and Rodionov, 1998, 2003; Rodionov and Assel 2000)

PNA

TNH

Background

CILER
Cooperative Institute for Limnology
and Ecosystems Research
University of Michigan

GLERL
Great Lakes Environmental Research Laboratory

- A 30-day ice forecast model has been developed using linear regression, with teleconnection indices as input (Assel et al, 2004). However, many of them are not independent.

- Further, the Great Lakes are positioned at the edge of active centers of some teleconnection patterns. Impact of a specific teleconnection may be not significant. Combined effects should be considered.

- **ENSO and AO/NAO** (Arctic Oscillation/North Atlantic Oscillation) are the first two **leading** and **independent** patterns of inter-annual climate variability in North Hemisphere. And have large impacts on North America.
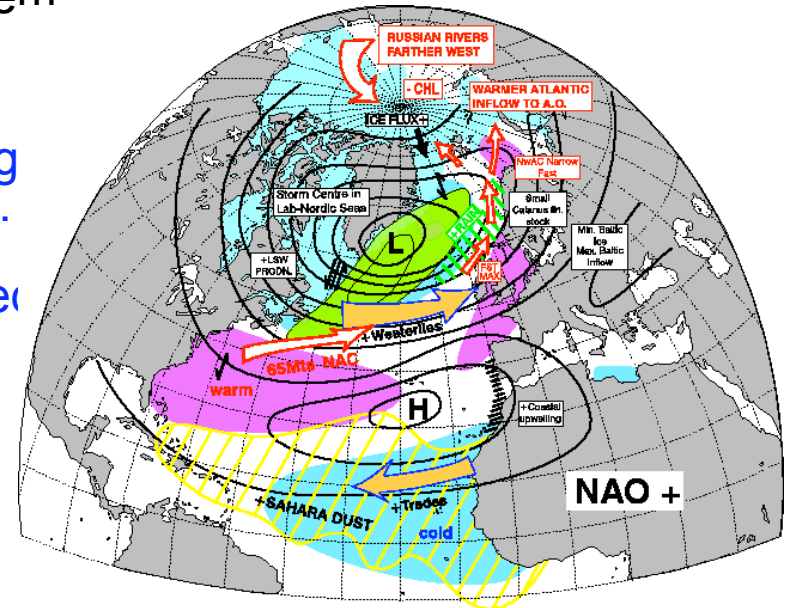
This study will focus on the impacts of ENSO and AO on the Great Lakes ice cover.

Data

1 46 yrs (1963-2008) Great Lakes Annual Maximum Ice Coverage (in percentage)

2 NCEP/NCAR reanalysis atmospheric fields with resolution of 2.5 degrees (Lat/Lon): 1948-2008 monthly
700 hPa (mb) height (Z700), sea level pressure (SLP), surface air temperature (SAT)

3 Climate indices
(1) ENSO: Nino3.4 index (Averaged SSTA over 5 N to 5S, 170W to 20W) ,was obtained from NOAA CPC (Climate Prediction Center) 1950-2008

(2) AO index
defined as normalized leading PC (principal component) of winter SLP anomalies poleward of 20ºN latitude.1948-2008
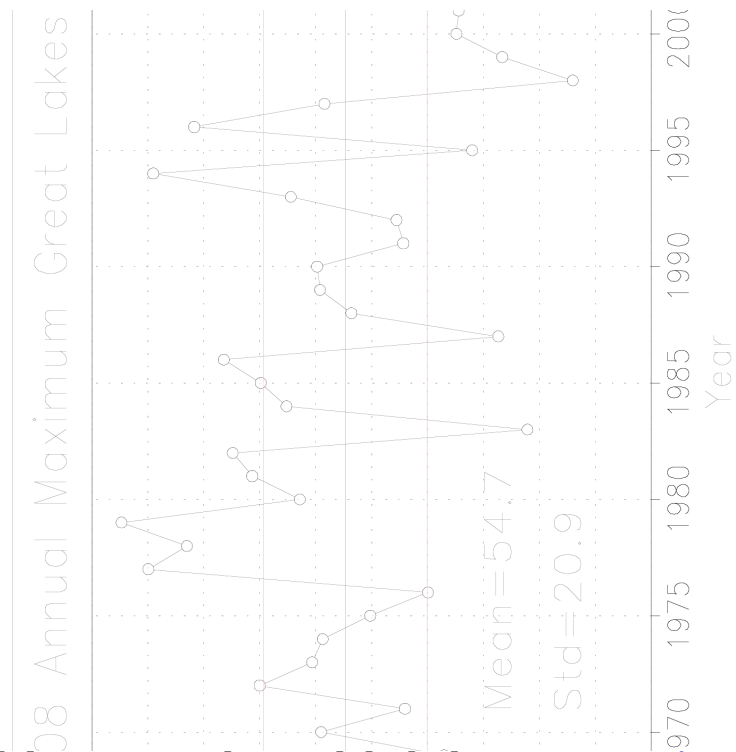
There were 13 winters with anomalous high ice cover (> mean+0.7*STD=69.4)
   1963 1967 1972 1977 1978 1979 1981 1982 1985 1986 1994 1996 2003
   (blue are –AO yrs)

And also 13 winters with anomalous low Ice Cover (< mean-0.7*STD=40.01)
   1964 1966 1969 1976 *1983 1987 1995 1998* 1999 2000 2001 2002 2006
   (Yellow are El Nino yrs)

   -AO signal in the high ice cover
   winters and El Nino signal in the low
   ice cover winters

Composite winter 700 mb height anomaly for high (left) and low (right) ice cover (atmospheric circulation anomaly)
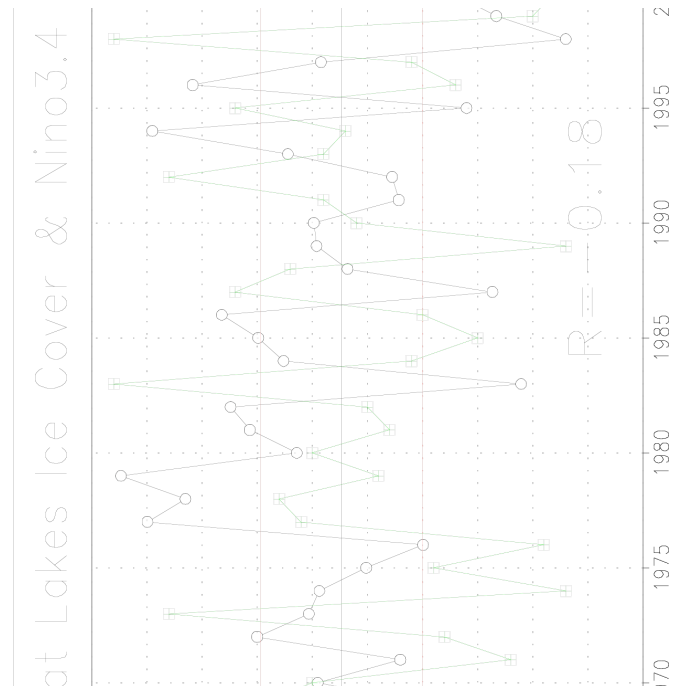

Mixture of AO & PNA

TNH
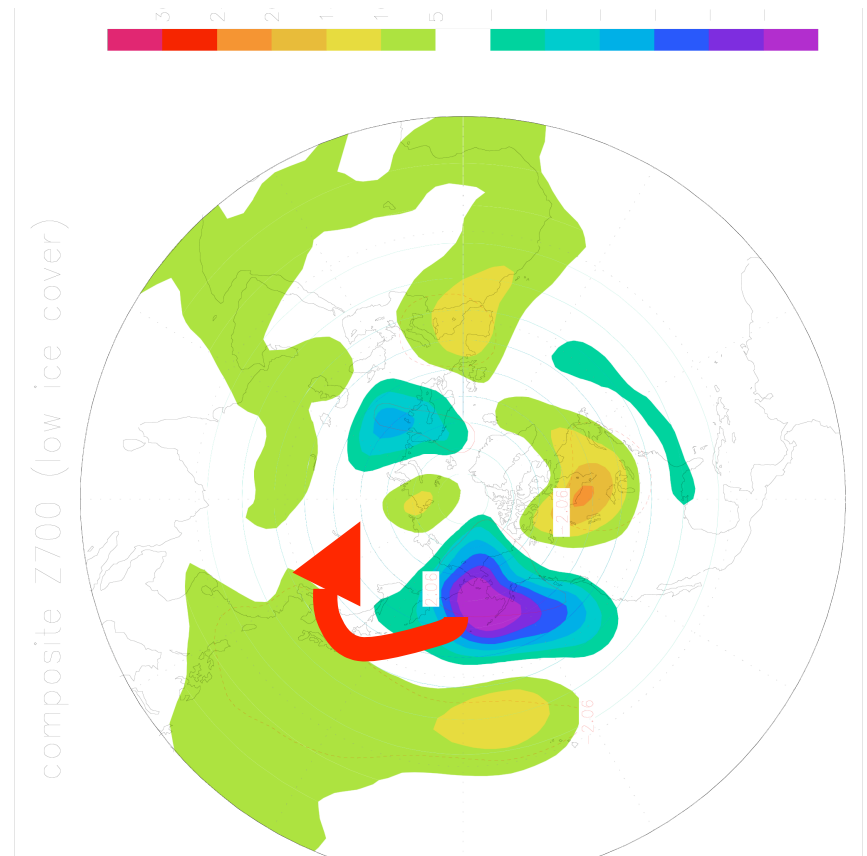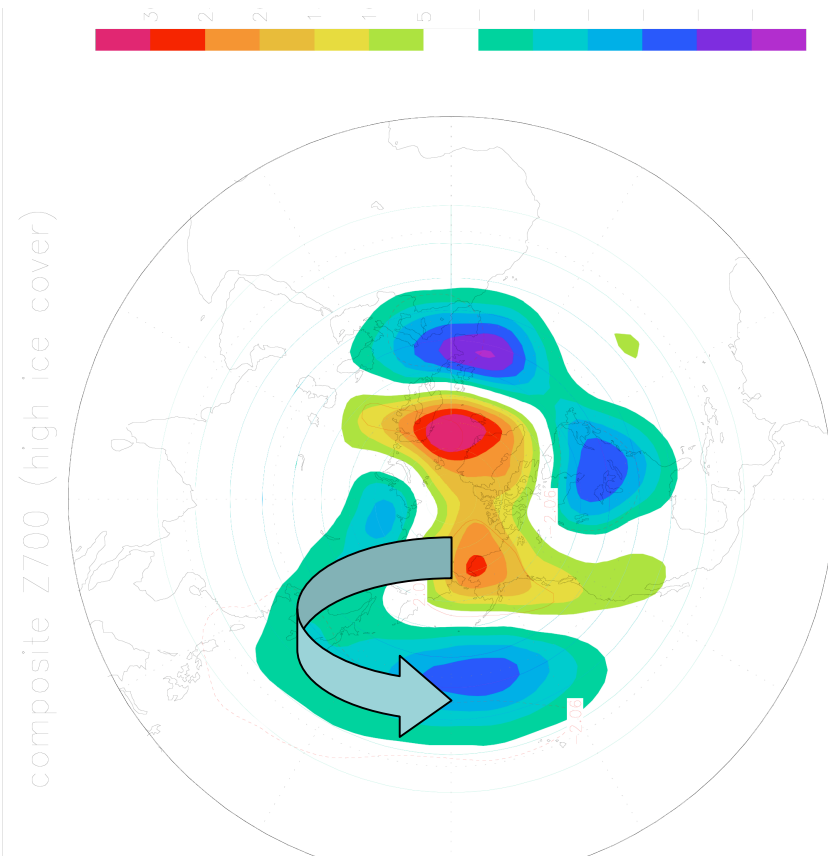
Composite winter SAT anomalies for high (left) and low (right) ice cover
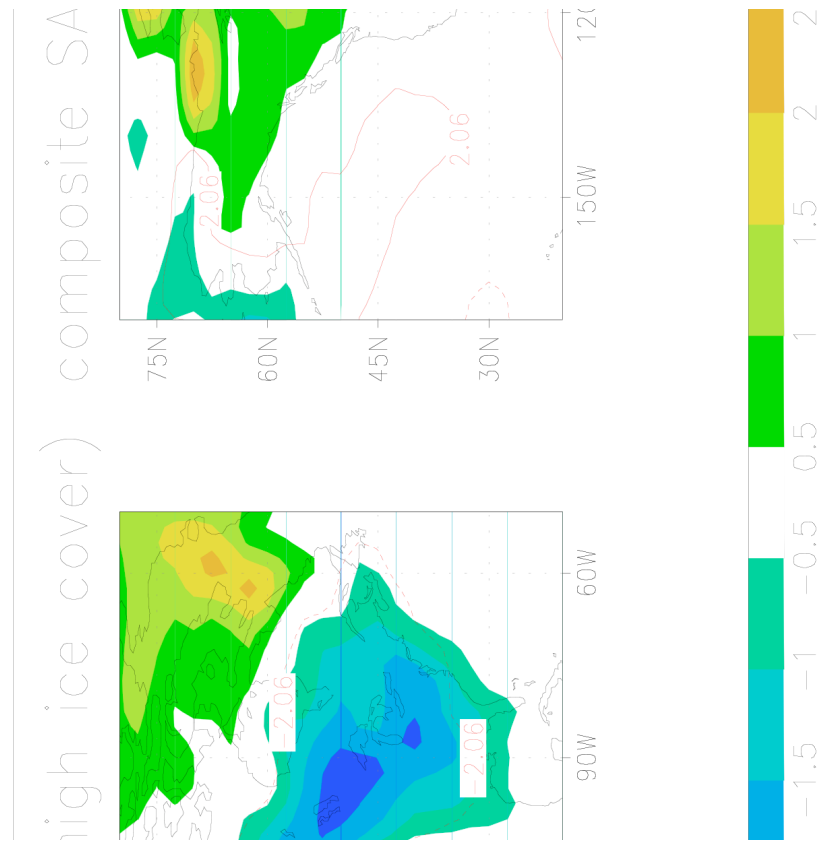
In winters with high ice, significant negative SAT anomalies appear over the Great Lakes region.

In winter with low ice cover, significant positive SAT anomalies occupy much of North America, except southern part of US.

Relationship btw ENSO and Ice Cover

The correlation btw them is not significant (-0.18) .
But it does not mean ENSO has no impact on Ice
cover on the Great Lakes.

ENSO and Ice cover

CILER
Cooperative Institute for Limnology
and Ecosystems Research
University of Michigan

GLERL
Great Lakes Environmental Research Laboratory

From 1963 to 2008, there were 15 El Nino events. Among them, 10 strong and 5 weak.

Of 10 strong El Nino events,
  7 winters with low ice cover,
  1 with high ice cover.
  2 normal: 1 slightly low and 1 slightly high
Of 5 weak El Nino events
    2 winters with high ice cover,
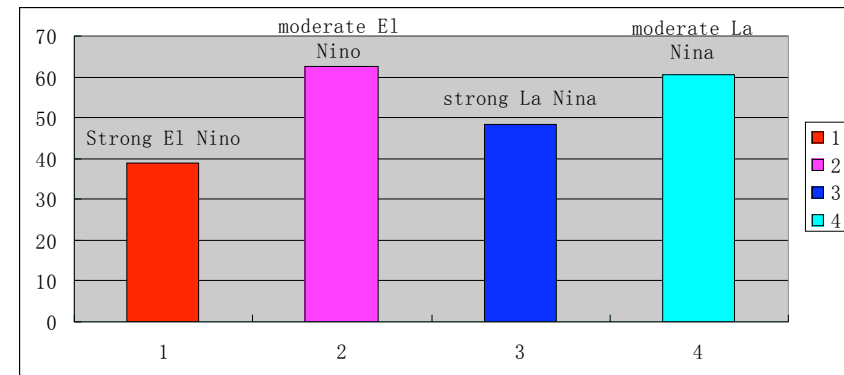   3 normal: 2 slightly low 1 slightly high,

There were 14 La Nina events.
Among them, 8 strong, 6 weak

3 winters with high ice cover. 3 low. 8 normal

of 8 strong La Nina events: 1 high 3 low   4
    normal (2 slightly low and 2 slightly high)
of 6 weak La Nina events: 2 high 1 low   3
   normal (1 slightly low, and 2 slightly high)

Average ice coverage during El Nino/La Nina

Only strong El Nino events are associated with significant low ice cover.
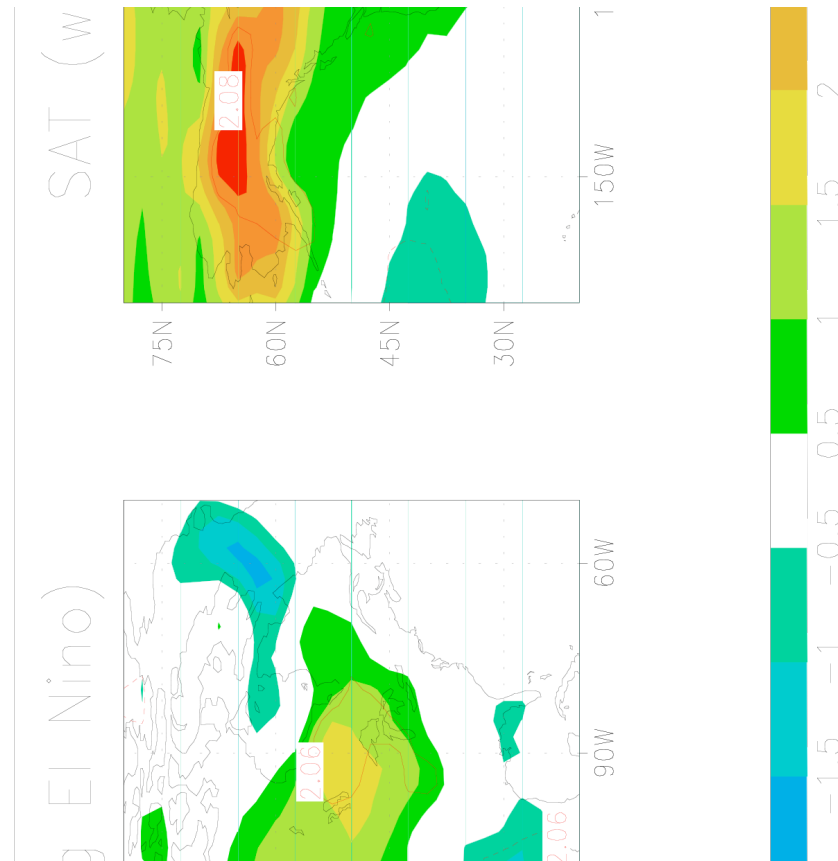Effects of weak El Nino and La Nina events on Great Lakes are not remarkable

Composite 700 mb height anomalies for strong and weak El Nino (circulation anomaly**)**

Composite Z700 (strong El Nino)

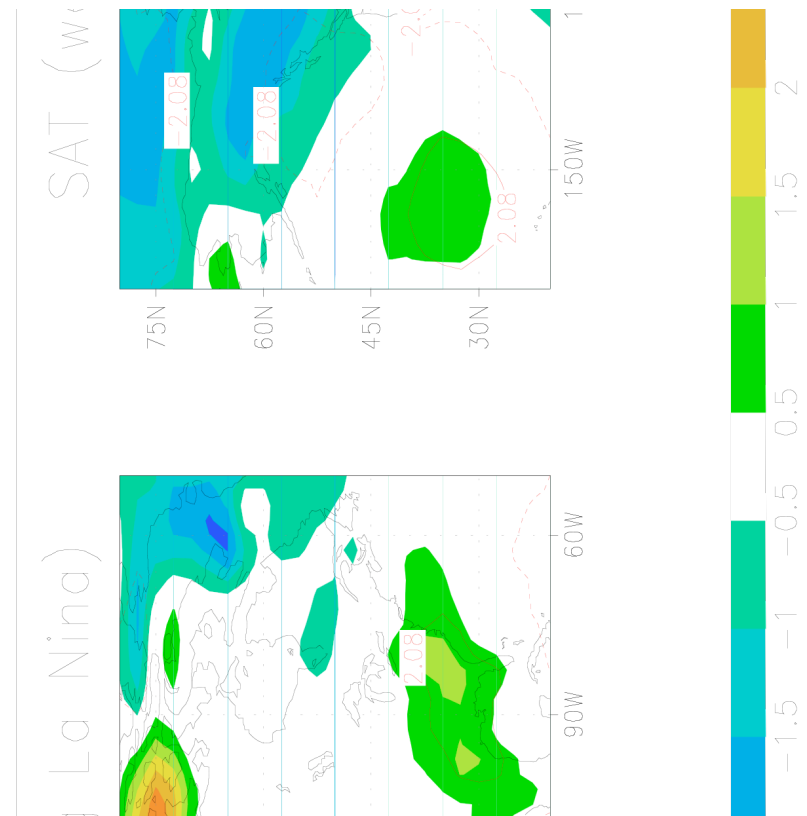TNH pattern

Composite Z700 (weak El Nino)

PNA
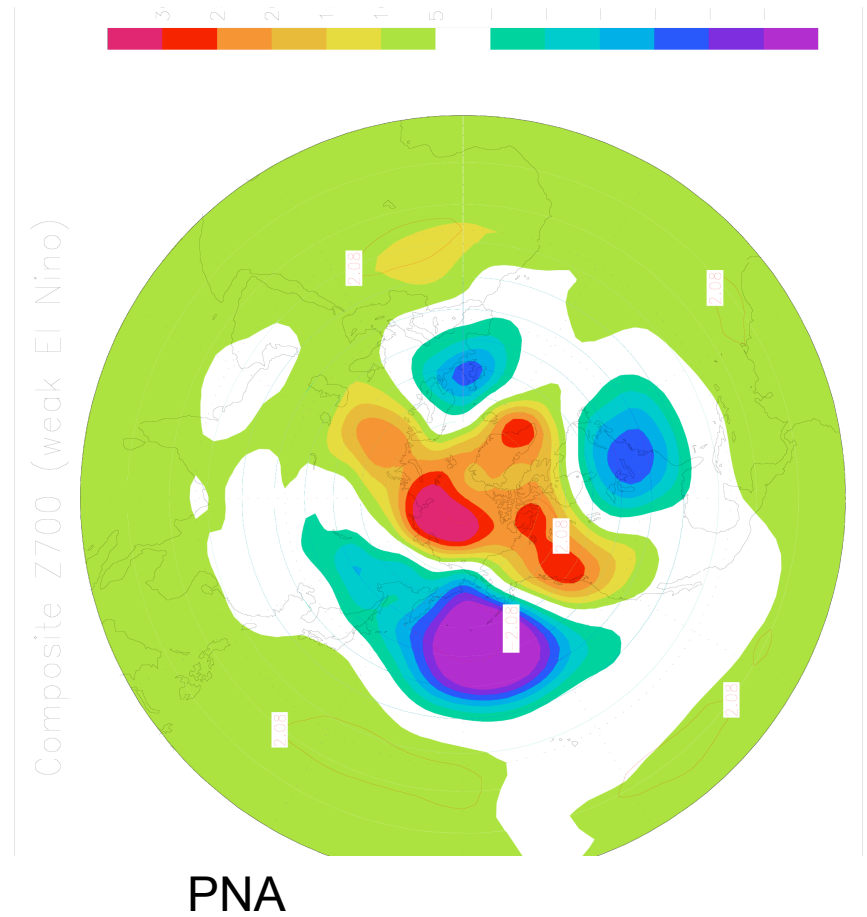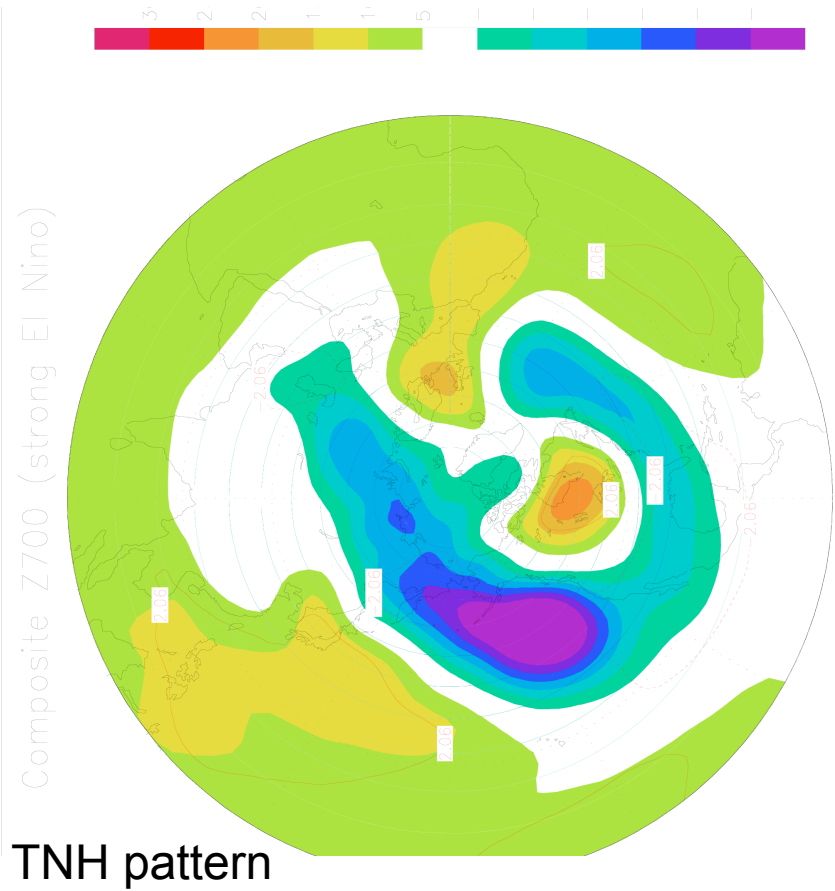
Composite winter SAT anomaly in North America for strong (left) and weak (right) El Nino

During strong El Nino, above normal temp. appear over Alaska, W. Ca and Great Lakes

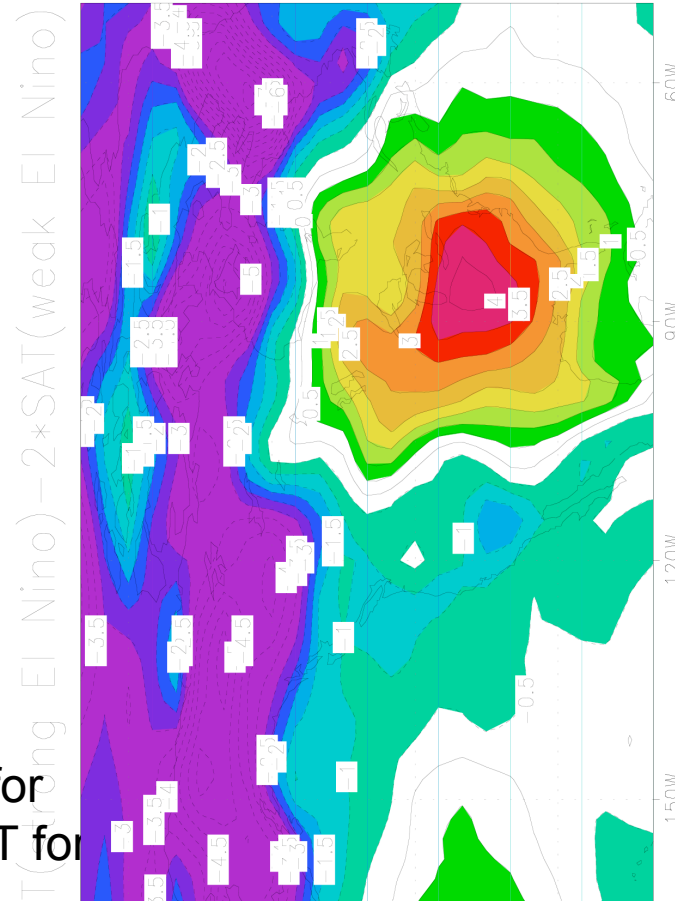During weak El Nino, no significant SAT anomalies over the Great Lakes

Composite SAT anomaly for strong (left) and weak (right) La Nina

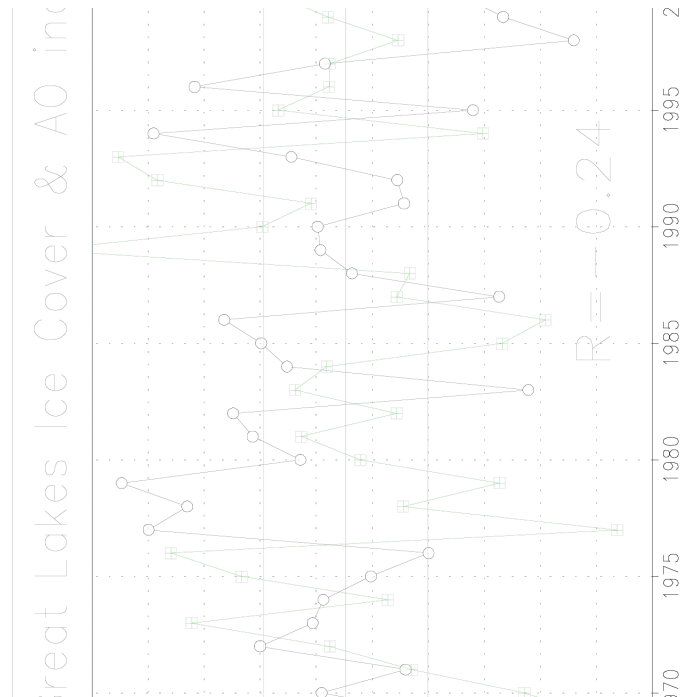During strong or weak La Nina, no remarkable anomalous SAT appear over the Great Lakes.

Nonlinear effect of El Nino on SAT

roughly estimated by SAT for strong El Nino minus 2*SAT for weak El Nino

Strong nonlinear signals in eastern US with center near Great Lakes

Relationship btw ice cover and AO

Also, similar as ENSO, the correlation btw ice cover and AO is not significant.

AO and Ice cover

Among 10 winters with -AO:

6 winters with high ice cover.
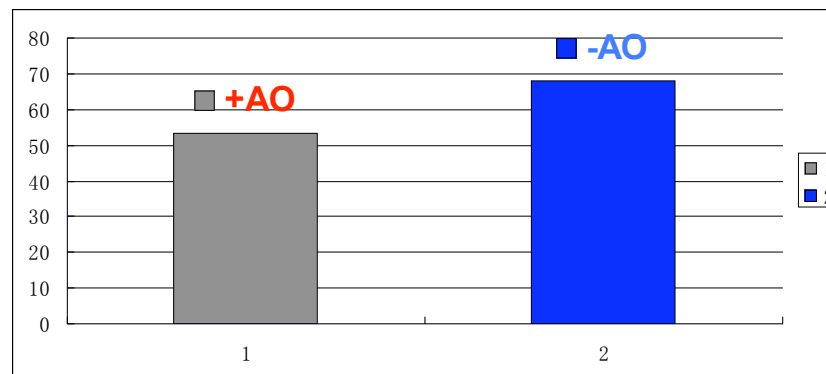
2 with low ice cover (co-occurred with strong El Nino),
2 with normal

Among 12 winters with +AO

4 winters with low ice cover (2 co-occurred with El Nino)

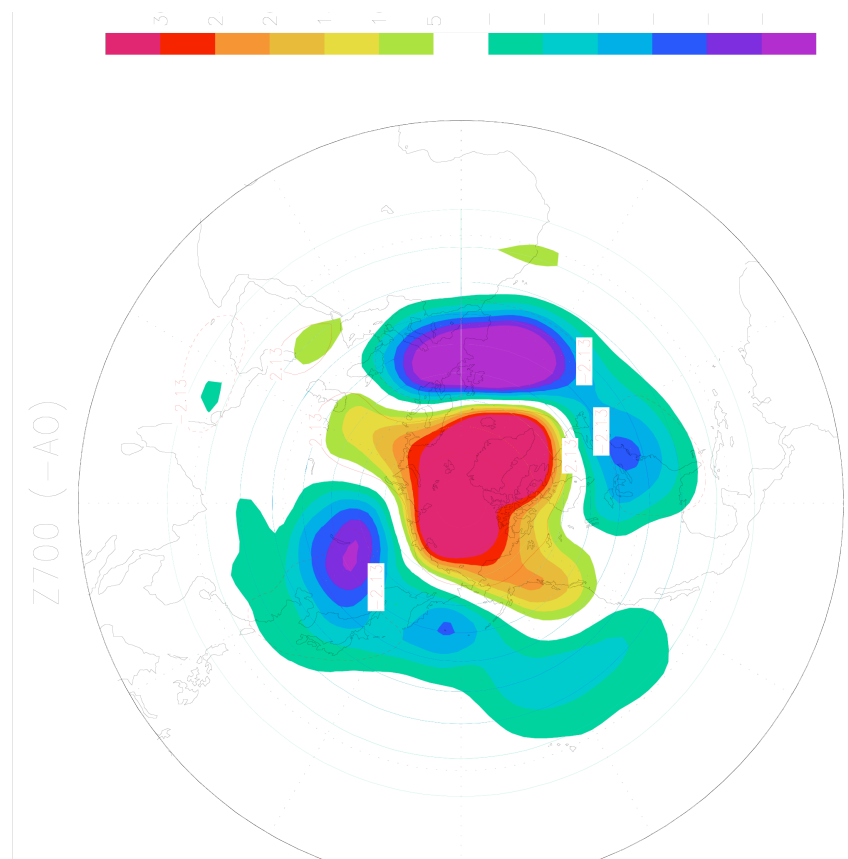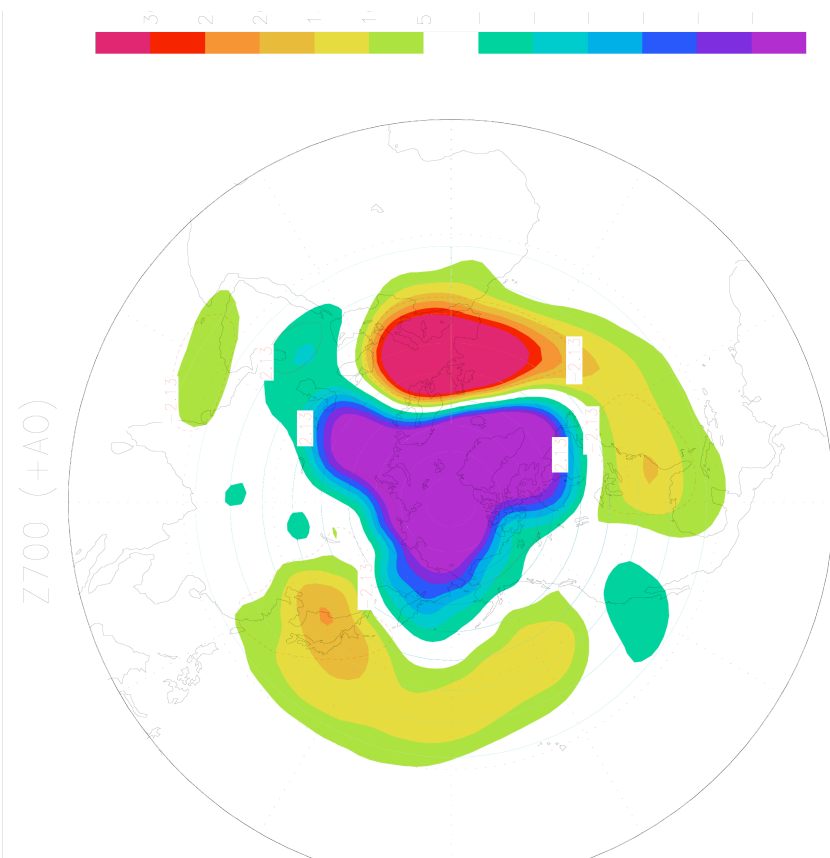8 winters with normal ice cover :
3 slightly low 5 slightly high.

5 +AO yrs co-occurred with La Nina
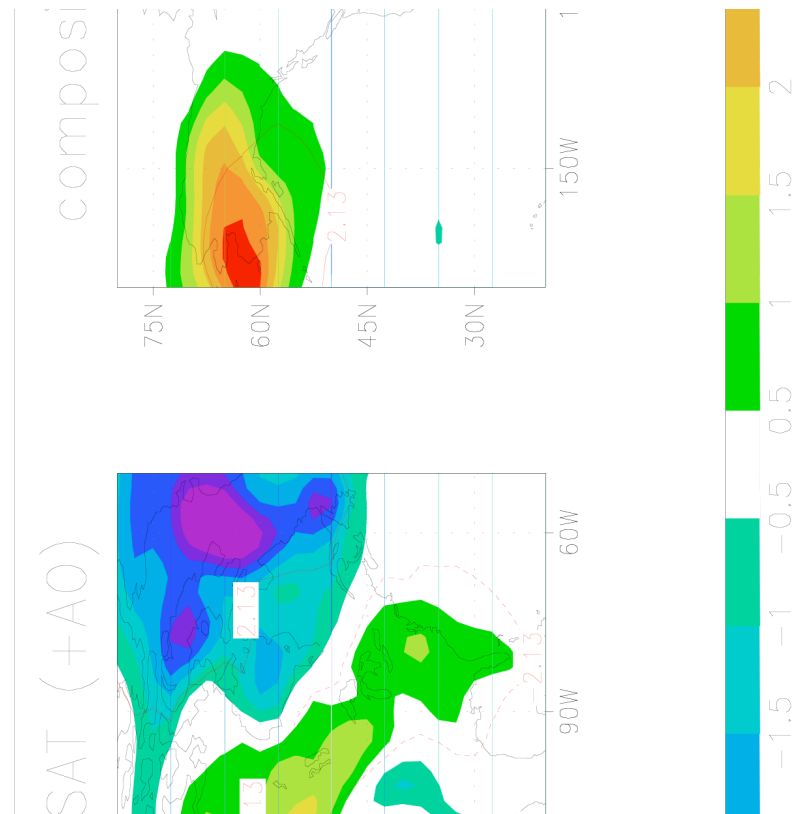

Average ice coverage for winters with +/-AO

Impact of –AO on the Great Lakes is more remarkable than that of +AO

# Composite winter 700 hPa height anomalies for +AO (left) and -AO (right)

Composite winter SAT anomalies for +AO (left) and -AO (right)

During +AO, the center of positive anomalies is located at western Canada. Great Lakes area is slightly warmer than normal

During –AO, significant negative anomalies appear over much of US with center near Great Lakes area.

Asymmetric SAT anomalies between –AO and +AO
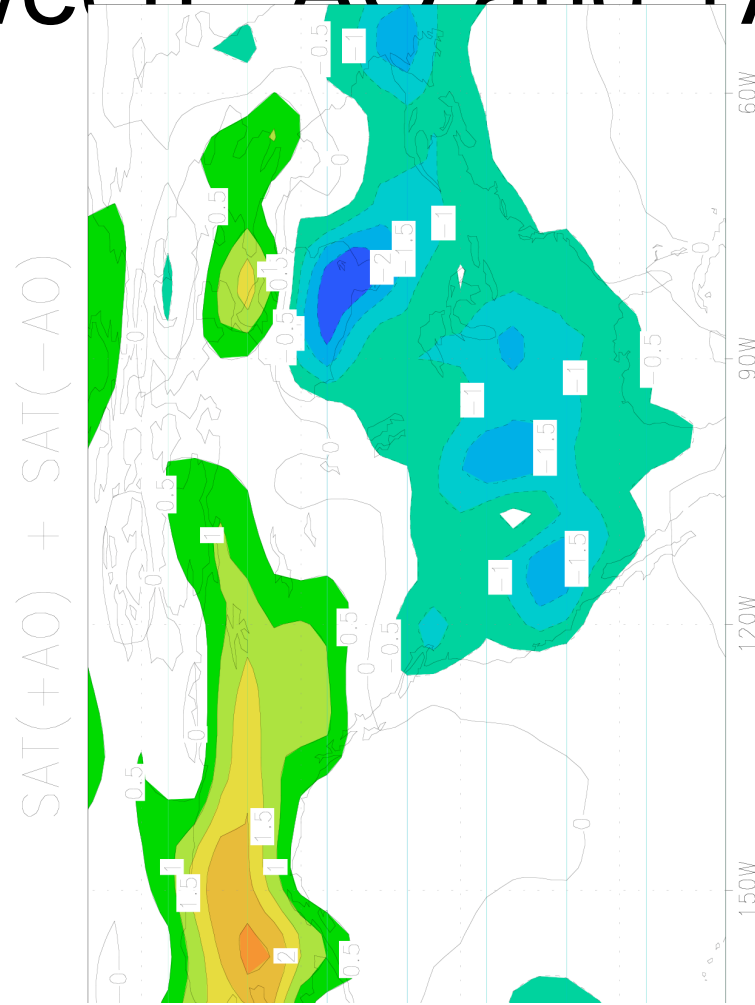
Summary

1 Strong El Nino and –AO explains about 50% of winters with low and high ice cover, respectively.

2 The impacts of ENSO and AO on the Great Lakes ice cover are nonlinear and asymmetric.

  (1) During strong El Nino, the Great Lakes tend to have low ice cover. The impacts of weak El Nino and La Nina are not significant. Especially, few La Nina events were associated with high ice cover
  (2) During -AO, the Great Lakes tend to have high ice cover. During +AO, ice cover on the Great Lakes tends to be slightly lower.

3 One possible cause of the nonlinear response to ENSO and AO is co-occurrence of AO and El Nino/La Nina
  Co-occurrence of +AO (warm) and La Nina (cold) will enhance the nonlinearity, leading to normal ice cover due to cancellation each other.
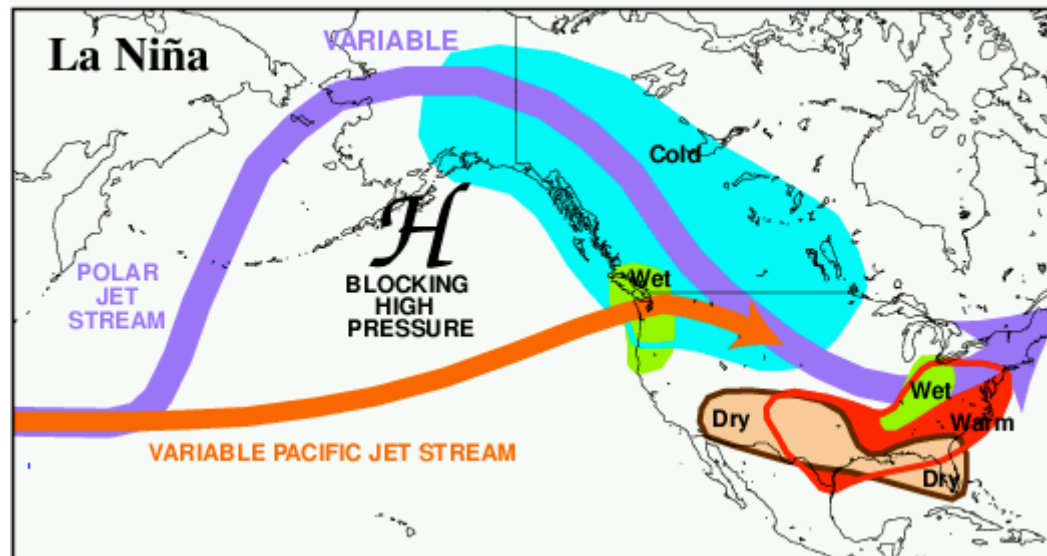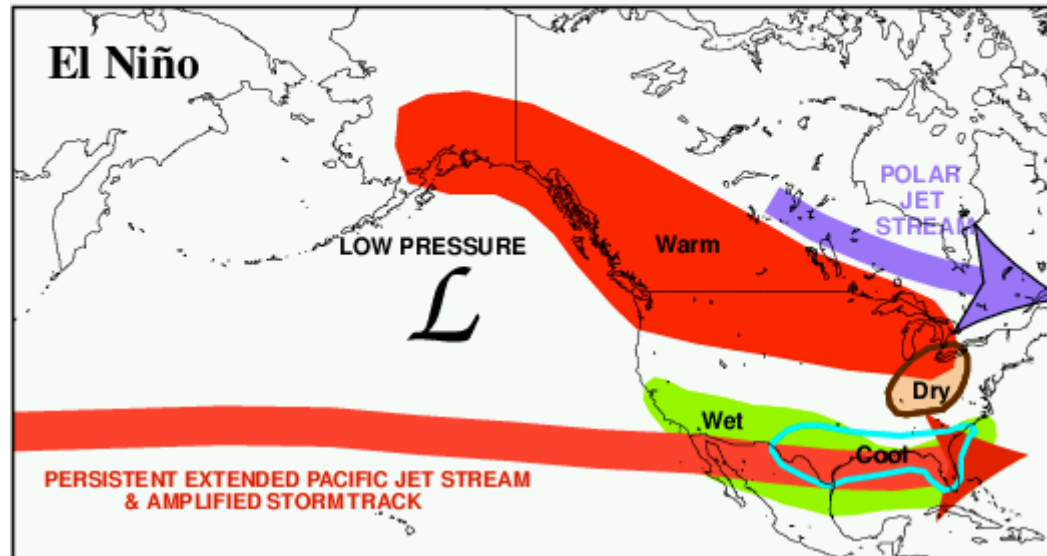
Thanks

Combination effects

	+AO/NAO (warm)	-AO/NAO (cold)
El Nino (warm)	**Extremely warm** 1973,1983,1992,1995,2007	Normal 1966,1969
La Nina (cold)	Normal 1975 1976 1989 2000 2008	Extremely cold 1965 1985 2001

TYPICAL JANUARY-MARCH WEATHER ANOMALIES
AND ATMOSPHERIC CIRCULATION
DURING MODERATE TO STRONG
EL NIÑO & LA NIÑA

- As an inverse of El Nino, we expected that during La Nina, ice cover on the Great Lakes should be higher than normal.

- And, we also expect that during the weak El Nino, ice cover should be moderate lower than normal.

- but the facts do not support this linear response view.